Regolith/Ice Stratigraphy in a Lunar Polar Coldtrap: Basis for a Lunar Ice Discovery Mission.

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Clementine evidence consistent with the existence of ice in permanently-shadowed areas near the south pole of the Moon (Nozette et al, 1996) would tend to confirm the view of Arnold (1979, 1987) that the rate of migration and deposition of water ice in permanent cold traps is greater than its rate of removal (eg. Lanzerotti, 1981). If this is the case, a range of possibilities exists for the physical state of ice deposits with respect to regolith formation and gardening processes. Although the water ice in the cold traps is expected to be deposited on a molecule-by-molecule basis, the rate of deposition of ice is a function of the source of the water. Water released anywhere on the Moon by micrometeoroid impact, including meteoritic water as well as water formed by the reduction of iron oxides by solar wind-implanted hydrogen, will migrate to the polar cold traps. The deposition rate of water is slow, perhaps amounting to perhaps 0.5mm/million years (Arnold. 1979) averaged over the permanently-shadowed area. On the other hand, a large comet could deposit a layer of ice on the order of a centimeter in thickness in a matter of days, although the integrated rate of addition of cometary water ice over a billion years might be similar to that contributed by micrometeoroids. If the thickness of a layer of comet ice is greater than the mean depth of gardening in the period between its deposition and its burial under a layer of impact debris or another layer of ice, a record of that comet impact will remain. If the rate of deposition of ice from all sources is greater than the rate of turnover of the regolith, a gradual buildup of an ice layer will occur, and in time only those craters that penetrate deeper than the ice thickness will bring regolith material to the surface, resulting in a patchy surface distribution of regolith-penetrating craters on an otherwise continuous ice sheet. If both conditions exist, there will be an ice stratigraphy in which comet ice layers are interspersed with general ice layers.

If the thickness of a comet ice layer is less than the mean depth of gardening, comet ice will be redistributed and become mixed with ice from other sources. If the total rate of ice deposition is less than the rate of turnover of the regolith, a more uniform, less patchy, ice-regolith mixture would result. A crude stratigraphy will always exist, in which the deeper deposits are older and richer in regolith material. As the turnover of the regolith is a stochastic process, even in cases of lower total rates of ice deposition, it could still be possible to find comet-ice layers though deposits continuous over significant distances would be rare.

Models for regolith gardening suggest that in a million years, 50% of the lunar surface is turned over one time by meteoroid impact to a depth of about 8 mm; in a billion years, 50% of the surface is turned over to a depth of 3-20 cm (Gault et al, 1974). The polar ice model developed by Arnold (1979) suggests that approximately 100 cm of ice has been deposited in the past billion years. Thus, if Arnold's model of ice deposition proves to be correct, there is a substantially higher rate of ice deposition than regolith turnover at the centimeter scale and a patchy surface ice distribution may exist, in which impacts that have excavated meter-deep or deeper craters have deposited regolith locally on an otherwise continuous ice sheet. In this model, comet ice layers a centimeter or greater in thickness have a relatively high probability of being preserved with continuous lateral extent. Although the uppermost few millimeters of a new comet ice layer will be gardened by micrometeoroid impact, new ice being deposited will gradually shield the deeper portions of the layer. Thus, between meter-deep impact craters within the cold traps, it may be possible to sample a stratigraphy, predominantly of ice, in which larger comet impacts have been recorded in a continuous sequence.

If the rate of deposition of ice is less than that predicted by Arnold (1979) or the rate of removal by sputtering or other phenomena is greater, the ratio of ice to regolith will be smaller and the icy rubble model envisioned by most previous studies will prevail. The abundance of ice in a thoroughly-mixed regolith will increase toward the surface because ice is

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being added at the surface and the turnover rate is greater nearer the surface.

The rate of addition of water to the Moon's surface by comets is problematical, because the flux is not known well and the mechanisms by which water might be retained by the Moon are uncertain. Arnold (1979) made an estimate of 10^{16} to 10^{17} grams of comet water (equivalent to approximately 100-1000 cm of ice if distributed uniformly across the existing cold traps) in the past 2 billion years. However, Shoemaker et al (1990) believe that comet impacts tend to dominate the largest crater-forming events on the Earth and Moon, and that comets with masses of 10^{17} grams strike the Moon at a rate of about 1^{-8}/yr. Retention of water on the Moon is probably better for lower-velocity impacts (short-period comets) than for higher velocity impacts (long-period comets); but, anything with regard to retention is merely speculation at this point. The total amount of cometary water, and the possible thickness of layers from individual comets could be larger or smaller than the figure suggested by Arnold (1979).

It is possible to distinguish between these models with experiments done on the lunar surface. The Lunar Ice Discovery mission proposes to do that by means of an instrumented surface rover, capable of landing in sunlit areas and conducting sorties into permanently shadowed areas. The rover will be equipped with a 1-meter drill and analytical instrumentation to determine the chemical and isotopic composition of ice. A camera system will be capable of observing the surface distribution of ice and rubble. The principal objectives of such a mission would be to determine the presence and characteristics of surface distribution of ice in the cold traps and the presence of an ice stratigraphic section. The instrumentation would also determine the nature of volatile species in the ice deposits, which are expected to be primarily water, but could include other volatiles and organic compounds. This mission has been proposed to the Discovery Program.

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